



# Transmutation of Radioactive Materials using Thermal Neutrons

Duke University and the Triangle Universities Nuclear Laboratory \*

C.R. Howell and W. Tornow

## The Security Problem:

There are 103 electric generation stations powered by nuclear reactors in operation in the U.S. today. These plants generate about 20% of the electrical power consumed in the U.S., and our reliance on nuclear power will likely increase substantially over the next 50 years as oil reserves are exhausted. At the present level of electric power consumption from nuclear reactors about 30 tons of plutonium and 120 tons of fission product are produced annually in the U.S.A. About three times this amount is produced collectively by the rest of the world. The people of this country and other major industrialized nations are faced with the critical issue of what to do with this waste stream of highly radioactive material. As a temporary solution in our country, these materials are placed in storage pools at each reactor site. The plan is to eventually start shipping these materials from the reactor sites for long-term storage in a national nuclear waste repository in Yucca Mountain in Nevada. Because this waste contains weapon-useful fissionable materials, the accumulation of it throughout the world creates a serious international security risk. Each country with these materials must maintain strict safeguards to prevent the loss of even small amounts to terrorist organizations or to nations with ambitions of acquiring nuclear weapons capabilities. One vulnerable repository may become a source of fissionable materials for the production of bandit nuclear weapons and can put all nations at great risk. This fragile situation will exist potentially forever. Clearly a better solution than simple storage is required if nuclear fission power is to become a major long-term energy source for the world. As a super power the U.S. must take responsibility for leading the world to a more secure long-term solution to this problem.

## A Solution is Accelerator-Driven Transmutation:

Because of the gravity of this issue in terms of the U.S. economy, public safety and national and international security, it is essential that policy makers are well informed of all the solutions to this problem that are technically feasible and economically practical. One proposed solution is to transmute the radioactive nuclei to stable isotopes using fission reactors that are based on the fast part of the neutron velocity spectrum. The size of the capital investment in the reactor and the associated chemical processing plant drive up the cost of the electricity generated by these plants considerably relative to the power from standard nuclear reactors. An alternative is to transmute the radioactive isotopes to stable nuclei using accelerator-driven nuclear fission reactors operating with a thermal neutron spectrum. In this design, a full fuel load does not provide sufficient numbers of neutrons to sustain the fission chain reaction. Instead, additional neutrons are provided by an accelerator. Also, plutonium and can be completely transmuted to materials that are not weapons useful. In this concept we propose to locate a transmutation reactor at each power-plant site, thus eliminating the issues associated with transporting radioactive materials over public highways and railways. This design also can be the basis of new reactors that burn mainly thorium, which does not produce weapons useful materials.

In comparison to other proposed solutions the full realization of accelerator-driven transmutation technology potentially will give an environmentally advantageous, more secure and more economically viable means of reducing the world's growing inventory of weapons-useful and highly radioactive nuclear waste. In addition, this technology offers a power reactor development path that separates the production of electricity from the creation of nuclear-weapons fissionable materials and from nuclear weapons technologies. Although accelerator-driven systems for waste transmutation have been under study in the U.S. for more than a decade, no actual experiment has been done in the U.S. to study the dynamic coupling of an accelerator to a neutron multiplying system. Researchers at the Triangle Universities Nuclear Laboratory (TUNL) are collaborating with the Accelerator-Driven Neutron Applications (ADNA) Corporation to conduct such studies for the purpose of developing an accelerator-driven nuclear-waste transmutator. Our approach is unique in that it uses a thermal neutron energy spectrum rather than fast neutrons. A graphite-lattice fission multiplying system has been constructed at TUNL and characterization measurements have begun in collaboration with the ADNA Corporation. The system is described, preliminary results from the first empirical studies are reported, and the proposed project development plan is presented.

\* Done in collaboration with the Accelerator-Driven Neutron Applications (ADNA) corporation.

## The Problem:

### Nuclear Weapons Material

(Plutonium, Neptunium)

- \*World-wide 120 tons produced per year by nuclear power reactors
- \*Easier to use than "weapons plutonium"
- \*Lasts hundreds of thousands of years (forever?)
- \*Stored in more than thirty nations
- \*Impossible to guard it "forever"

### Long-lived Radioactivity

Fission products ( $^{99}\text{Tc}$ ,  $^{129}\text{I}$ ,  $^{135}\text{Cs}$ )

By-products (Neptunium, Plutonium, Americium, Curium)

- \*Radioactive for hundreds of thousands of years
- \*No man-made containers will last that long
- \*Therefore we will rely on geologic confinement
- \*Scientifically there is one best place in the nation
  - Therefore one community (Nevada) gets all of the nations worst waste
  - Therefore the waste must travel to this one best site
  - Difficulty convincing the public that the waste will be confined for eons

## Proposed Project Agenda and Schedule:

### 1. Characterization of critical parameters of the graphite-moderated neutron multiplier system and development of reliable software model of the lattice: FY2003 - 2004

- develop neutron production target
- measure spectrum averaged neutron capture and induced fission rates on  $^{238}\text{U}$  and  $^{232}\text{Th}$
- measure neutron absorption rate in the graphite moderator
- measurement of  $k_{\text{eff}}$  for the lattice fully loaded with  $\text{UO}_3$
- calibrate the software model of the lattice using benchmark measurements and start using the computer modeling software to conduct design studies for the demonstration plant
- required funds: \$350k

### 2. Development of Demonstration System: FY2005 – 2007

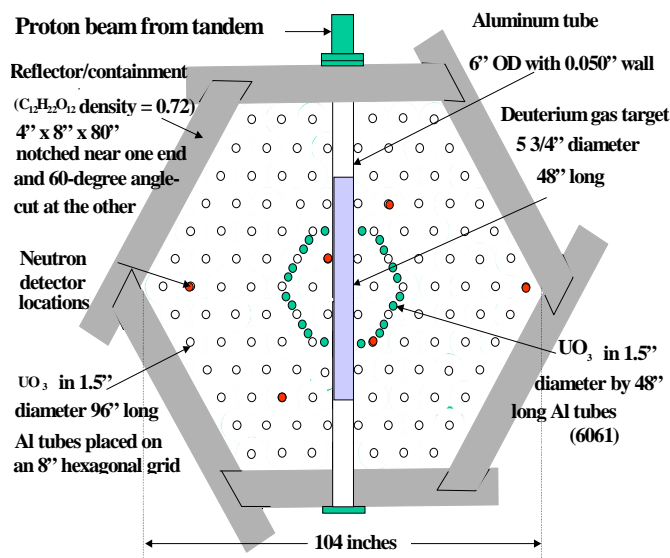
- fission power: initially 4 MW with upgrade to 40 MW
- engineering and construction of major parts:
  - molten salt fuel circulation system
  - heat exchangers and steam generators
  - accelerator drivers
  - neutron production target
  - operation and safety control systems

### 3. Complete construction and begin operation of Pilot Plant: by FY2011

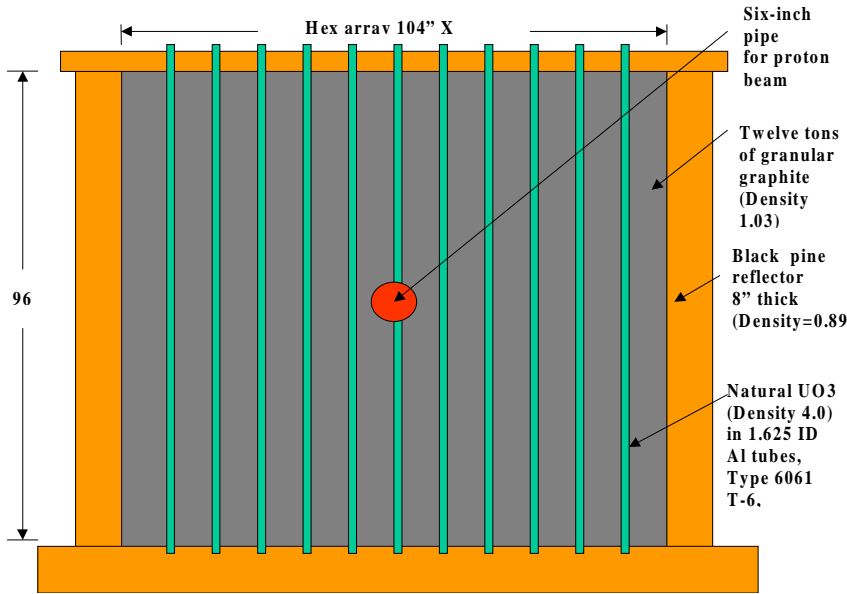
### 4. Begin general deployment of transmutators at nuclear power stations: by FY2015

### 5. Complete processing of nuclear waste from operating reactors by mid century

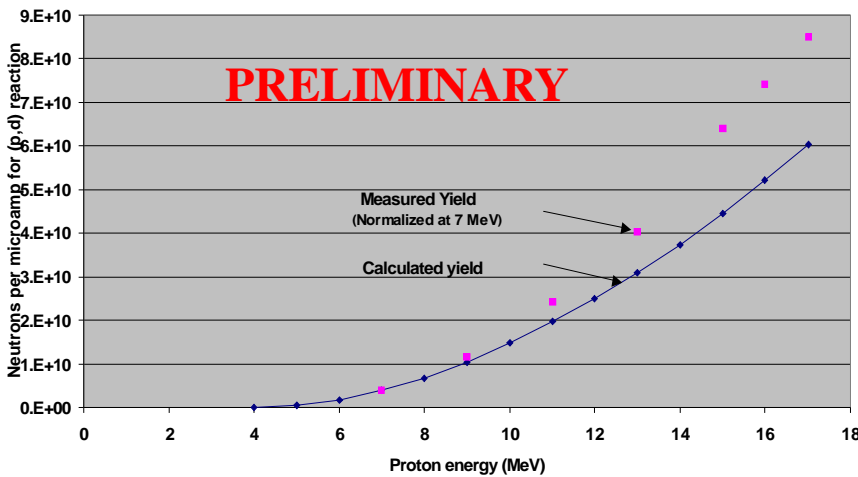
## Top view of Graphite lattice



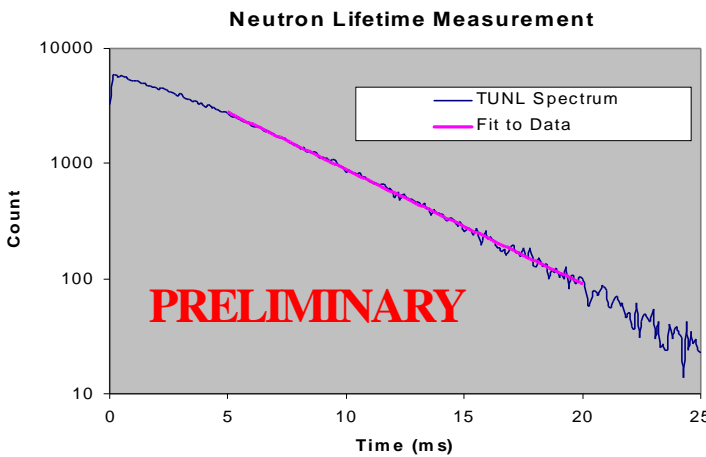
**Fig. 1.** Top view of the graphite lattice built by the ADNA Corporation and studied at TUNL. The system is a 8-ft diameter by 8-ft high cylinder filled with granular graphite for neutron moderation. It has 125 1.5-in diameter and 8-ft long aluminum tubes vertically mounted. The tubes are 8 inches apart and are arranged in co-centric hexagonal patterns as shown. A 6-in diameter aluminum pipe passes through the center perpendicular to the cylinder axis for placement of a target for neutron production by the proton beam. The walls of the lattice are constructed of 4-in thick by 8-in wide interlocking black pine beams.



**Fig. 2.** Vertical cross-sectional view of the graphite lattice. The vertical aluminum tubes hold 1.3 tons of  $\text{UO}_3$  to give a  $k_{\text{eff}} = 0.8$ . Wood was chosen as the material for the walls because it is a good neutron reflector.



**Fig. 3.** Measured neutron yield from a 48-in long gas deuterium target that was pressurized to stop the proton beam at each energy. The measured yields are compared to the calculated yields for the  $^3\text{H}(p,n)^2\text{p}$  reaction. Total nd breakup cross sections from Faddeev calculations were used for the pd breakup reaction. The increase in the actual yields over the predicted yields indicates that the  $^3\text{H}(d,n)$  reactions, which are induced by recoil deuterons from pd elastic scattering, contribute significantly to neutron production.



**Fig. 4.** Measurement of neutron lifetime in graphite lattice. The mean neutron life in the lattice is 4.4 ms.

**Contacts:** [howell@tunl.duke.edu](mailto:howell@tunl.duke.edu), [tornow@tunl.duke.edu](mailto:tornow@tunl.duke.edu),  
[bilpuch@tunl.duke.edu](mailto:bilpuch@tunl.duke.edu), [cbowman@cybermesa.com](mailto:cbowman@cybermesa.com)